

Docket No. AUS9-2000-0572-US1

**APPARATUS AND METHOD FOR IMPLEMENTING SWITCH INSTRUCTIONS
IN AN IA64 ARCHITECTURE**

RELATED APPLICATIONS

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The present invention is related to commonly assigned and co-pending U.S. Patent Applications 09/671,876 (Attorney Docket No. AUS9-2000-0569) entitled "APPARATUS AND METHODS FOR IMPROVED DEVIRTUALIZATION OF METHOD CALLS", 09/671,770 (Attorney Docket No. AUS9-2000-0570) entitled "APPARATUS AND METHOD FOR AVOIDING DEADLOCKS IN A MULTITHREADED ENVIRONMENT", 09/671,477 (Attorney Docket No. AUS9-2000-0573) entitled "APPARATUS AND METHOD FOR DETECTING AND HANDLING EXCEPTIONS", 09/671,771 (Attorney Docket No. AUS9-2000-0584) entitled "APPARATUS AND METHOD FOR VIRTUAL REGISTER MANAGEMENT USING PARTIAL DATA FLOW ANALYSIS FOR JUST-IN-TIME COMPILATION", 09/671,873 (Attorney Docket No. AUS9-2000-0585) entitled "APPARATUS AND METHOD FOR AN ENHANCED INTEGER DIVIDE IN AN IA64 ARCHITECTURE", 09/671,874 (Attorney Docket No. AUS9-2000-0586) entitled "APPARATUS AND METHOD FOR CREATING INSTRUCTION GROUPS FOR EXPLICITLY PARALLEL ARCHITECTURES", and 09/671,475 (Attorney Docket No. AUS9-2000-0587) entitled "APPARATUS AND METHOD FOR CREATING INSTRUCTION BUNDLES IN AN EXPLICITLY PARALLEL ARCHITECTURE", filed on even date herewith and hereby incorporated by reference.

BACKGROUND OF THE INVENTION

30 **1. Technical Field:**

The present invention is directed to an apparatus and method for implementing switch instructions in an

IA64 architecture.

2. Description of Related Art:

- Dense switch instructions, such as tableswitch in
- 5 Java bytecode, provide for multi-way branching based on an input integer and a range of integer values. Known systems implement such switching instructions in one of two ways. First, multiple compare/branch pairs may be utilized followed by a branch to a default address.
- 10 Alternatively, a check to see if an input index value falls within a specified range may be made with a target address being selected from an array of such addresses if the index does fall within the range. If the index does not fall within the range, a default address is provided.
- 15 The address is then loaded in a branch register and an execution branch to that address is performed.

- Both approaches set forth above require multiple comparisons which take up processing cycles that may otherwise be used for other useful work. Thus, it would
- 20 be advantageous to have an apparatus and method for implementing a switch instruction which reduces the number of comparisons required to perform the switch instruction. It would further be beneficial to have an apparatus and method to perform such switching
- 25 instructions in an IA64 architecture based data processing device.

SUMMARY OF THE INVENTION

5 The present invention provides an apparatus and
method for implementing a dense switch instruction in the
IA64 architecture. With the present invention, a first
register is loaded with a value equal to a power of 2 (a
single bit), and a second register is used to develop a
10 shift amount based on the index (comparand) value of the
switch. The first register is then shifted by the shift
amount in the second register and the result is loaded
into a contiguous range of IA64 predicate registers with
the result being that at most 1 of the predicate
15 registers will receive the value 1 while all others will
receive the value 0. The loading of the predicates is
followed by a series of predicated branch instructions
such that there will be one branch for each of the
targets designated by the switch instruction. The
20 qualifying predicates used to gate these branches are the
same as those that were loaded in the previous step. The
series of predicated branches is followed by an
unpredicated branch to the default target address.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

10 **Figure 1** is an exemplary block diagram of a distributed data processing system according to the present invention;

Figure 2A is an exemplary block diagram of a data processing system according to the present invention;

15 **Figure 2B** is an exemplary block diagram of a data processing system according to the present invention; and

Figure 3 is a flowchart outlining an exemplary operation of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides an apparatus and method for implementing switch instructions in an IA64 architecture data processing device. The IA64 architecture data processing device may be a stand-alone device, a client device, a server device, or the like, and may be a part of a distributed network. Thus, the following figures are provided as a description of some of the possible data processing system in which the present invention may be implemented.

With reference now to the figures, and in particular with reference to **Figure 1**, a pictorial representation of a distributed data processing system in which the present invention may be implemented is depicted. Distributed data processing system **100** is a network of computers in which the present invention may be implemented. Distributed data processing system **100** contains a network **102**, which is the medium used to provide communications links between various devices and computers connected together within distributed data processing system **100**. Network **102** may include permanent connections, such as wire or fiber optic cables, or temporary connections made through telephone connections.

In the depicted example, a server **104** is connected to network **102** along with storage unit **106**. In addition, clients **108**, **110**, and **112** also are connected to a network **102**. These clients **108**, **110**, and **112** may be, for example, personal computers or network computers. For purposes of this application, a network computer is any computer, coupled to a network, which receives a program

or other application from another computer coupled to the network. In the depicted example, server **104** provides data, such as boot files, operating system images, and applications to clients **108-112**. Clients **108**, **110**, and **112** are clients to server **104**. Distributed data processing system **100** may include additional servers, clients, and other devices not shown. In the depicted example, distributed data processing system **100** is the Internet with network **102** representing a worldwide collection of networks and gateways that use the TCP/IP suite of protocols to communicate with one another. At the heart of the Internet is a backbone of high-speed data communication lines between major nodes or host computers, consisting of thousands of commercial, government, educational, and other computer systems, that route data and messages. Of course, distributed data processing system **100** also may be implemented as a number of different types of networks, such as, for example, an Intranet or a local area network.

Figure 1 is intended as an example, and not as an architectural limitation for the processes of the present invention. The present invention may be implemented in the depicted distributed data processing system or modifications thereof as will be readily apparent to those of ordinary skill in the art.

With reference now to **Figure 2A**, a block diagram of a data processing system which may be implemented as a server, such as server **104** in **Figure 1**, is depicted in accordance to the present invention. Data processing system **200** may be a symmetric multiprocessor (SMP) system including a plurality of processors **202** and **204** connected

to system bus **206**. Alternatively, a single processor system may be employed. Also connected to system bus **206** is memory controller/cache **208**, which provides an interface to local memory **209**. I/O Bus Bridge **210** is
5 connected to system bus **206** and provides an interface to I/O bus **212**. Memory controller/cache **208** and I/O Bus Bridge **210** may be integrated as depicted.

Peripheral component interconnect (PCI) bus bridge **214** connected to I/O bus **212** provides an interface to PCI
10 local bus **216**. A modem **218** may be connected to PCI local bus **216**. Typical PCI bus implementations will support four PCI expansion slots or add-in connectors. Communications links to network computers **108-112** in **Figure 1** may be provided through modem **218** and network
15 adapter **220** connected to PCI local bus **216** through add-in boards.

Additional PCI bus bridges **222** and **224** provide interfaces for additional PCI buses **226** and **228**, from which additional modems or network adapters may be
20 supported. In this manner, server **200** allows connections to multiple network computers. A memory mapped graphics adapter **230** and hard disk **232** may also be connected to I/O bus **212** as depicted, either directly or indirectly.

Those of ordinary skill in the art will appreciate
25 that the hardware depicted in **Figure 2A** may vary. For example, other peripheral devices, such as optical disk drive and the like also may be used in addition or in place of the hardware depicted. The depicted example is not meant to imply architectural limitations with respect
30 to the present invention.

The data processing system depicted in **Figure 2A** may

be, for example, an IBM RISC/System 6000 system, a product of International Business Machines Corporation in Armonk, New York, running the Advanced Interactive Executive (AIX) operating system.

5 With reference now to **Figure 2B**, a block diagram of a data processing system in which the present invention may be implemented is illustrated. Data processing system **250** is an example of a client computer. Data processing system **250** employs a peripheral component
10 interconnect (PCI) local bus architecture. Although the depicted example employs a PCI bus, other bus architectures such as Micro Channel and ISA may be used. Processor **252** and main memory **254** are connected to PCI local bus **256** through PCI Bridge **258**. PCI Bridge **258** also
15 may include an integrated memory controller and cache memory for processor **252**. Additional connections to PCI local bus **256** may be made through direct component interconnection or through add-in boards. In the depicted example, local area network (LAN) adapter **260**,
20 SCSI host bus adapter **262**, and expansion bus interface **264** are connected to PCI local bus **256** by direct component connection. In contrast, audio adapter **266**, graphics adapter **268**, and audio/video adapter (A/V) **269** are connected to PCI local bus **256** by add-in boards
25 inserted into expansion slots. Expansion bus interface **264** provides a connection for a keyboard and mouse adapter **270**, modem **272**, and additional memory **274**. SCSI host bus adapter **262** provides a connection for hard disk drive **276**, tape drive **278**, and CD-ROM **280** in the depicted
30 example. Typical PCI local bus implementations will support three or four PCI expansion slots or add-in

connectors.

An operating system runs on processor **252** and is used to coordinate and provide control of various components within data processing system **250** in **Figure**

5 **2B**. The operating system may be a commercially available operating system such as OS/2, which is available from International Business Machines Corporation.

An object oriented programming system such as Java may run in conjunction with the operating system and may
10 provide calls to the operating system from Java programs or applications executing on data processing system **250**. Instructions for the operating system, the object oriented operating system, and applications or programs are located on storage devices, such as hard disk drive
15 **276** and may be loaded into main memory **254** for execution by processor **252**. Hard disk drives are often absent and memory is constrained when data processing system **250** is used as a network client.

Those of ordinary skill in the art will appreciate
20 that the hardware in **Figure 2B** may vary depending on the implementation. For example, other peripheral devices, such as optical disk drives and the like may be used in addition to or in place of the hardware depicted in **Figure 2B**. The depicted example is not meant to imply
25 architectural limitations with respect to the present invention. For example, the processes of the present invention may be applied to a multiprocessor data processing system.

The present invention provides an apparatus and
30 method for implementing switch instructions in an IA64 architecture. Although the present invention may operate on a variety of computer platforms and operating systems,

it may also operate within a Java runtime environment. Hence, the present invention may operate in conjunction with a Java virtual machine (JVM) yet within the boundaries of a JVM as defined by Java standard
5 specifications.

The JVM is the name of a virtual computer component that actually executes Java programs. Java programs are not run directly by the central processor but instead by the JVM, which is itself a piece of software running on
10 the processor. The JVM allows Java programs to be executed on a different platform as opposed to only the one platform for which the code was compiled. Java programs are compiled for the JVM. In this manner, Java is able to support applications for many types of data
15 processing systems, which may contain a variety of central processing units and operating systems architectures. To enable a Java application to execute on different types of data processing systems, a compiler typically generates an architecture-neutral file format -
20 the compiled code is executable on many processors, given the presence of the Java run-time system.

The Java compiler generates bytecode instructions that are nonspecific to a particular computer architecture. A bytecode is a machine independent code
25 generated by the Java compiler and executed by a Java interpreter. A Java interpreter is part of the JVM that alternately decodes and interprets a bytecode or bytecodes. These bytecode instructions are designed to be easy to interpret on any computer and easily
30 translated on the fly into native machine code.

The present invention is equally applicable to either a platform specific environment, i.e. a

traditional computer application environment loading modules or native methods, or a platform independent environment, such as an interpretive environment, e.g., a Java environment loading classes, methods and the like.

- 5 The only limitation on the data processing system and operating environment of the present invention is that the architecture be an IA64 architecture. The preferred embodiment of the present invention will be described in terms of an IA64 architecture operating in Java and
10 having a Java virtual machine (JVM).

- The IA64 architecture is described in the "Intel IA-64 Architecture Software Developer's Manual" available for download from <http://developer.intel.com/design/Ia-64/downloads/24531702s.htm>, which is hereby
15 incorporated by reference. Briefly, IA64 allows a compiler or programmer to explicitly group instructions to be executed concurrently. The IA64 architecture provides a set of 64 single bit predicate registers which can be used to control instruction execution. A
20 predicate register can be associated with an instruction as a "qualifying predicate." When the qualifying predicate is true, the instruction executes normally. When the qualifying predicate is false, the instruction will not modify the architectural state, thereby acting
25 essentially as a NOP instruction.

- The present invention provides a mechanism by which switch instructions may be implemented in the IA64 architecture. The present invention will be described with reference to the Java bytecode tableswitch.
30 However, other types of switch instructions, such as dense or semi-dense switch statements in C, may be implemented using the mechanism of the present invention.

The Java bytecode tableswitch provides a default target address, a low value, a high value, and an array of target addresses. The bytecode tableswitch takes an integer index as an input parameter and logically

5 functions as follows:

1) If the index is less than the low value or higher than the high value, a branch is made to the default target address; and

2) Otherwise, the low value is subtracted from the
10 index and the result is used to index into the array of target addresses and a branch is made to the selected target.

The present invention exploits the IA64 architecture's provision of predicate registers and
15 parallel instruction execution to efficiently implement a switch instruction, such as a Java tableswitch instruction. The use of the present invention to perform the switch instruction is limited to instances where the number of branch targets, excluding default, is less
20 than or equal to number of usable predicate registers provided in the IA64 architecture.

As mentioned above, the current IA64 architecture provides a set of 64 single bit predicate registers which can be used to control instruction execution. Thus, the
25 present invention is limited to instances where the number of branch targets is less than or equal to 63, i.e. there are 63 of the 64 predicate registers available with the first predicate register, p0, being a read-only register that always returns 1.

30 The invention uses a contiguous range of predicate registers starting with any predicate register other than p0. The number of predicate registers in the range will

be (high-low +1). Note that for switches where (high-low +1) is 10 or fewer, it may be advantageous to select a range that includes only the scratch predicates p6 through p15 (defined by software convention and described
 5 in Intel's "IA-64 Software Conventions and Runtime Architecture Guide"). In this way the predicate registers need not be preserved and restored.

The following processes are performed using the present invention:

- 10 1) a range of predicate registers is selected such that there are as many predicate registers in the range as there are entries in the target address array. For example if we have 10 targets in our target address array we may chose predicates p6 through p15.
- 15 2) if the low value is less than the lowest predicate selected (lowpredicate), a register regA is set to $2^{**}(\text{lowpredicate} - \text{low value})$ and another register, regB, is set to the index (if the index is already in a register, that register will be used instead of regB);
 20 otherwise, regA is set to $2^{**}\text{lowpredicate}$ and regB is set to index - low value.

3) regA is then shifted to the left by the value of regB, and regA is moved to the predicate register set using the IA64 instruction:

25

mov pr = regA, mask

where mask identifies a contiguous range of (high-low+1) predicate registers starting with lowpredicate. Only the
 30 specified range is loaded into the predicate register set with the other predicate registers being unaffected.

A number of predicated branches (high-low + 1)

follow. The first branch has the first target address from the target address array as its destination and is qualified by lowpredicate. Each successive branch uses the next target address array entry and is qualified by the next higher predicate. A final unpredicated branch follows which branches to the default address.

The shifting of regA by a value (index-low) stored in regB is a mechanism by which the particular branch that is to be executed is identified. As mentioned above, instruction branches identified by a predicate register are only executed if the predicate register value is 1. Thus, by shifting the regA value by the regB value, a particular predicate register, associated with the instruction branch to be executed, is identified.

Note that with the above mechanism, only one of the branches will actually be taken. Further, if the index is out of the range (i.e. The index is lower than low value or higher than high value), the single bit loaded into regA will be shifted out of the bit range (or will not be shifted into the bit range for example when low is 1 and index is 0) that is moved to the predicate registers thereby resulting in only the default branch being taken.

Thus, the present invention provides a mechanism by which a switching instruction may be implemented in the IA64 architecture. The particular mechanism provided eliminates the need to check for out of range values, as is required in the conventional switching instruction implementations, such as Java tableswitch bytecode. Furthermore, theoretically all of the branches can be executed in parallel on an IA64 processor yielding extremely low latency.

Figure 3 is a flowchart outlining an exemplary operation of the present invention. As shown in **Figure 3**, the operation starts with the selection of a predicate range (lowpredicate-highpredicate) such that the number of predicates in the range is equal to the number of entries in the target address array (step **310**). A determination is made as to whether the low value is lower than lowpredicate (step **320**). If so, the value in regA is set to $2^{**}(\text{lowpredicate} - \text{low value})$ and regB is set to index (step **330**); otherwise, the value in regA is set to $2^{**}\text{lowpredicate}$ and regB is set to index - low value (step **340**). RegA is then shifted to the left by the value of regB (step **350**) and a range of bits from regA is moved to the corresponding predicate registers (step **360**). A set of (high-low +1) predicated branches follow with a non-predicated branch to the default target following the predicated branches (step **370**). The operation then ends.

The present invention provides a mechanism by which the predicate registers available in the IA64 architecture may be used to perform switching instructions. By using the predicate registers in the manner described above, the number of instructions that must be performed is reduced, thereby increasing the efficiency of the system. The number of instructions is reduced by eliminating the need to perform boundary checks on the high and low values for the switch instruction. Also if the lowest predicate in the selected range is greater than low value the step of subtracting low value from index can be avoided.

As mentioned above, the present invention may be

used to implement a semi-dense switch statement. In order to implement a semi-dense switch statement with the current invention merely fill in the "missing" entries in the branch target array with the default address and
5 treat it as a dense switch statement.

It is important to note that while the present invention has been described in the context of a fully functioning data processing system, those of ordinary skill in the art will appreciate that the processes of
10 the present invention are capable of being distributed in the form of a computer readable medium of instructions and a variety of forms and that the present invention applies equally regardless of the particular type of signal bearing media actually used to carry out the
15 distribution. Examples of computer readable media include recordable-type media such a floppy disc, a hard disk drive, a RAM, and CD-ROMs and transmission-type media such as digital and analog communications links.

The description of the present invention has been
20 presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in
25 order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.